

Properties of Sea Grass and Sand Flat Sediments from the Intertidal Zone of St. Andrew Bay, Florida¹

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ABSTRACT: Organic and carbonate carbon and textural properties of the substrates underlying *Halodule wrightii* and *Thalassia testudinum* sea grass beds in the intertidal zone of St. Andrew Bay, Florida were compared to adjacent unvegetated sand flats by physiographic divisions within the bay and to the subtidal slopes of the bay. Sea grass and sand flat sediments were principally fine-grained quartz sands. The mean particle-size of the sea grass sediments were finer-grained than those of the sand flats only in the west arm and lagoon of the bay. Size-frequency distributions of the sea grass sediments were generally slightly more negatively skewed and more leptokurtic than those of the sand flats. The sea grass sediments were less well sorted than were the sand flat sediments. The average organic and carbonate carbon contents of the sea grass beds were 1.9-fold greater than that of the sand flats but much less than that of the subtidal sea grass meadows. In the areas of pollution, sea grasses were absent; near this area *Halodule wrightii* was the dominant sea grass.

Introduction

Sea grasses play a critical role in the coastal marine environments (Thayer et al. 1975), yet there is continuing destruction of sea grass beds by developments of large scale waterfront housing, industrial and civic construction, and pollution. Because of these impacts and the association these plants have with their sediments, attention has been directed to the need for evaluating the various types of substrates in which sea grasses grow. The sedimentary environments of subtidal sea grasses have been the subject of several studies, as in those of Ginsburg and Lowenstam (1958), Wood et al. (1969), Marshall and Lukas (1970), and Scoffin (1970). In the intertidal zone, however, delineation of sedimentary properties

in the sea grass beds and sand flats have received less attention. This study attempts to describe quantitatively the particle size and carbon content of the substrate underlying sea grass beds and of adjacent unvegetated sand flats and the extent pollution restricts the distribution of these sea grasses in the intertidal zone of a shallow estuarine complex on the northwestern coast of Florida.

Description of Area

The study area, the intertidal zone of St. Andrew Bay, is located in northwest Florida on the northeastern shore of the Gulf of Mexico; the approximate coordinates are 85°42'W and 30°09'N. The St. Andrew Bay complex consists of a shallow estuarine tidal embayment of four bays: West Bay, North Bay, East Bay, and St. Andrew Bay proper (Fig. 1). The principal source of fresh water for the system, Econfina Creek, had a mean discharge of 537 cfs over the 31 year period

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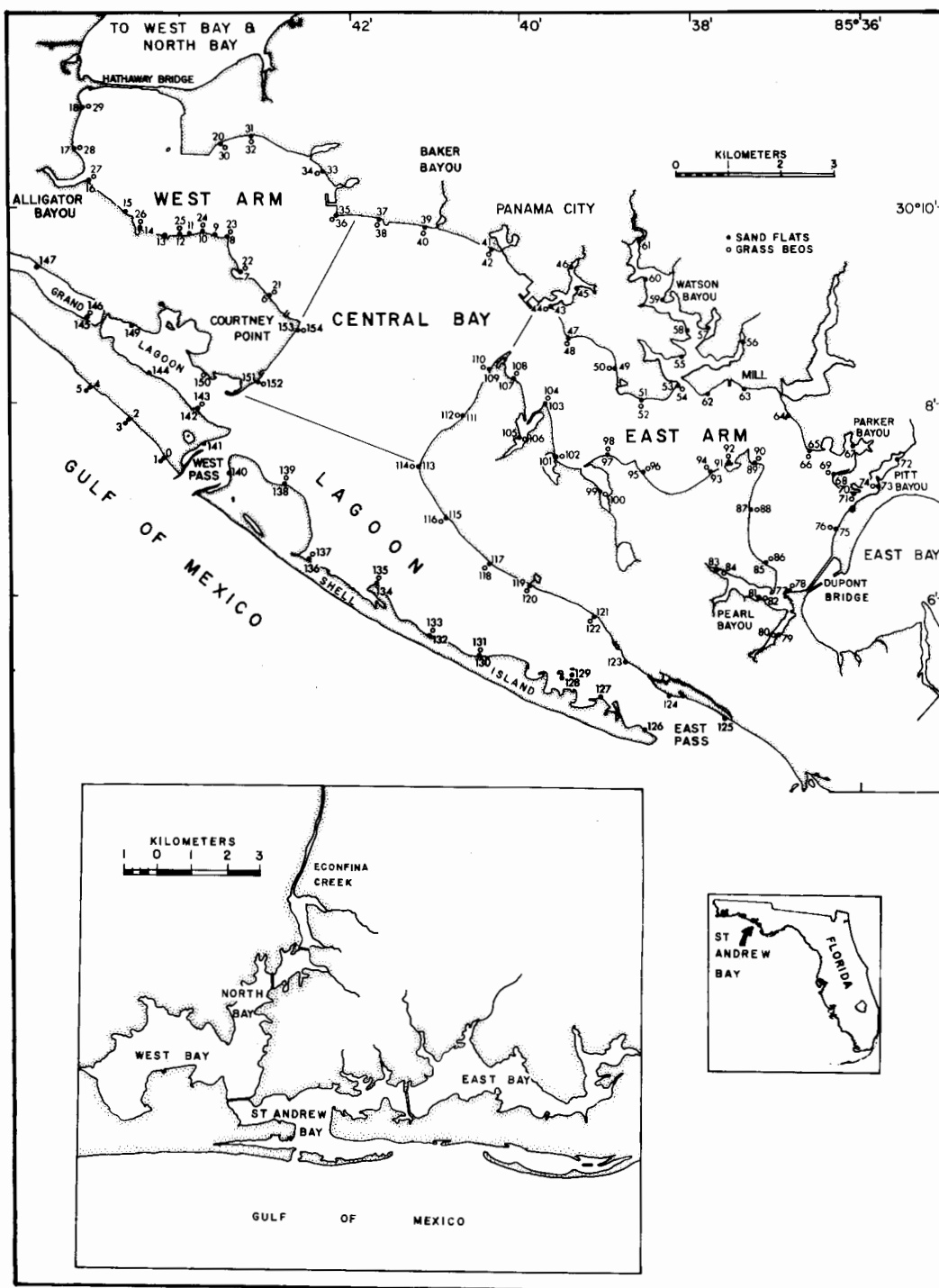


Fig. 1. The St. Andrew Bay estuarine system; location of intertidal stations. Sand flats indicated by dots and sea grass beds by circles.

TABLE 1. Average values of statistical parameters of (A) both sand flat and sea grass sediments in the intertidal zone of St. Andrew Bay; (B) intertidal sediments of the Lagoon at East Pass only; (C) subtidal slopes of the bay; (D) intertidal sediments from the Gulf of Mexico; graphic mean (M_z); inclusive graphic standard deviation (SD); inclusive graphic skewness (SK_1); graphic kurtosis (K_G); total carbon (TC); organic carbon (OC); and calcium carbonate ($CaCO_3$).

Area	Sample No.	M_z ϕ	SD	SK_1	K_G	TC %	OC %	$CaCO_3$ %
(A) Intertidal of Bay								
East Arm	39	2.15	0.96	-.24	1.62	0.93	0.65	2.38
Central Bay	14	2.19	0.53	-.06	1.43	0.42	0.29	1.10
West Arm	30	2.15	0.99	0.00	2.26	0.61	0.43	1.44
Bayous	27	2.07	0.82	-.24	1.28	1.20	1.04	1.34
Lagoon	38	1.99	0.52	-.20	1.20	0.49	0.26	2.01
(B) Intertidal of Lagoon								
East Pass	13	1.90	0.51	-.23	1.24	0.43	0.17	2.19
(C) Slopes of Bay								
Subtidal	115	2.70					1.27	
(D) Gulf of Mexico								
Intertidal	47	1.76	0.70	-.04	1.00	0.17	0.06	0.66

from 1935 to 1966 (McNulty et al. 1972). The tide is principally diurnal, with a mean range of 0.4 m (Salsman et al. 1966). There are 12 known point sources of pollution bordering St. Andrew Bay in the east and west arms, which include diverse industrial and private waste discharges and a Kraft process pulp mill at Panama City that has been in operation for about 40 years (EPA 1975).

St. Andrew Bay, which covers the lower reaches of the estuarine system, was divided into four physiographic divisions approximating the natural configurations of the bay: West Arm, East Arm, Central Bay, and Lagoon. A fifth physiographic designation, Bayous, included all indentations off the bay, such as Watson Bayou (Fig. 1).

Sea grasses occurring in the intertidal zone are principally *Halodule wrightii*, shoal grass, and with lesser frequency *Thalassia testudinum*, turtle grass. Of the 59 sampled sea grass substrates, *Halodule* was found at 23, *Thalassia* at 9, and a mixture of both at 27. The sampled sea grass beds were located on the upper periphery of more luxuriant beds that flourished at subtidal depths and were not from the main body of the sea grass meadow. Exposure of these patches of sea grasses began when the tide was slightly below mean low water. Some degree of exposure occurred on at least 126 days of the year based on predicted tides, but because of the effect of the wind on the

shallow waters of the bay, exposure was more frequent and extensive (Marmer 1954). Subtidal sea grass beds extended around the study area.

Procedures

Surficial sediments were collected at approximately 1 km intervals around the intertidal zone of St. Andrew Bay with a stainless steel plug sampler (0.16 m²). The plug was forced into the substrate by hand, sediment excavated around it, and the core retained in the plug, and transferred, surface upright, to a glass jar. One hundred and forty-eight samples were taken, 89 near the upper tide mark in sand flats, and 59 near the lower tide limit in sea grass beds within the bay (Fig. 1). Also collected, at monthly intervals, were 47 samples from six sites in the intertidal zone of the Gulf of Mexico adjacent to West Pass and 115 samples from the subtidal slopes of St. Andrew Bay. All sediment nomenclature is based on Shepard's (1954) ternary classification of Gulf of Mexico sediments. The gravelly sand notation was used at two stations where the sediment contained more than 10% gravel; this consisted primarily of shells and shell fragments in this area.

Samples were taken to the laboratory where a subsample, removed for determining moisture content, was immediately weighed and air-dried. The remaining por-

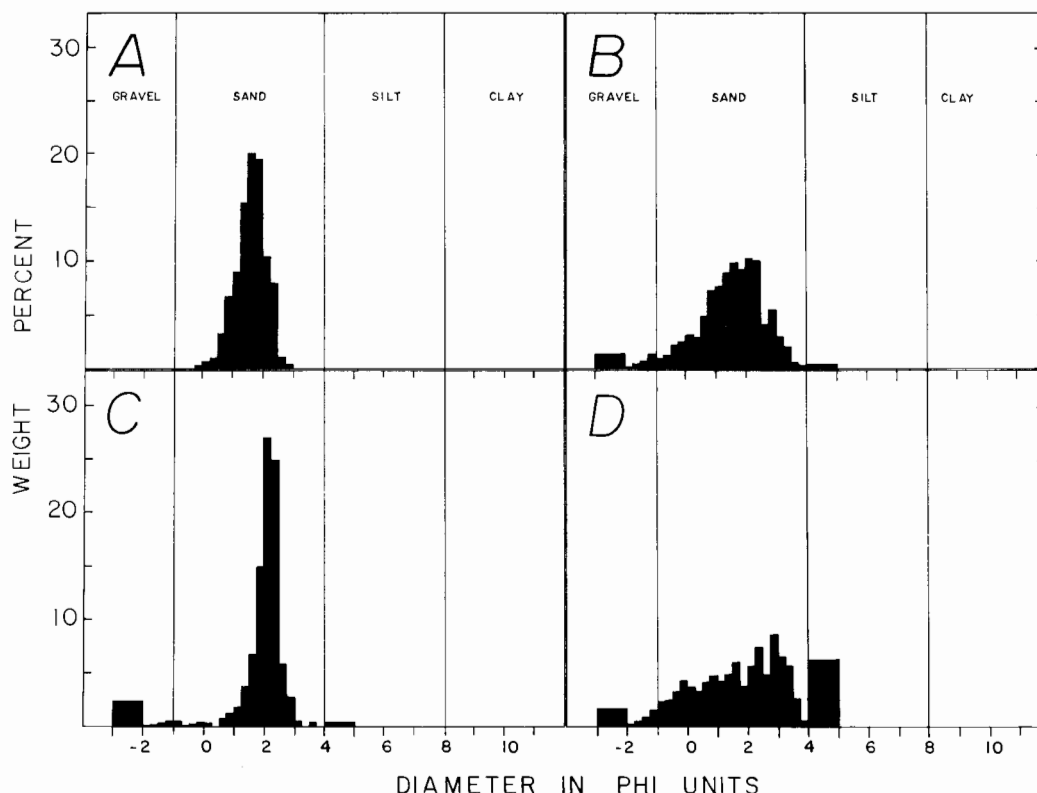


Fig. 2. Grain-size frequency distributions of sediments from St. Andrew Bay: A. Size-frequency distribution of sediment from sand flat in East Pass of Lagoon showing moderately well-sorted substrate with mode shifted slightly to coarse side; B. Sediment from sand flat in East Arm showing poor sorting with decreased kurtosis of size-frequency distribution; C. Sediment from *Halodule* bed on south shore of Lagoon showing spread of size-frequency distribution; D. Sediment from sand flat in polluted Watson Bayou showing polymodal character and decreased kurtosis of size-frequency distribution.

tion of the sample was then frozen. From a thawed sample, the upper 3 cm was removed, air-dried, and divided in a micro-splitter for particle analyses. The sample for particle size analysis was soaked in acetone for 15 minutes to remove most of the organic matter, disaggregated on an ultrasonic cleaner for 15 minutes, aspirated dry, and sieved through a series of 7.6 cm sieves at quarter phi intervals by agitation for 15 minutes on a shaker. If pipetting were necessary, a subsample was taken without drying the sediment, treated with acetone, rinsed, and wet-sieved. Salts were removed from the silt-clay fraction by aspirating with Pasteur-Chamberland type filters. Sodium hexametaphosphate was used as a peptizing agent (Krumbein and Pettijohn 1938; Folk 1968). Statistical parameters were computed from Folk and Ward (1957).

Total carbon and organic carbon were determined using a LECO 75-100 Automatic 70-Second Carbon Analyzer. (Reference to trade names does not constitute endorsement by the National Marine Fisheries Service, NOAA.) For analysis, two subsamples were prepared, one for total carbon and the other for organic carbon. The organic carbon content was obtained by analysis of the sediment after acidification with a 6% HCl solution at approximately 50 °C to remove carbonates. All tests and standards were run in triplicates. The difference between percent carbon content in the total carbon determination and the percent carbon in the organic carbon determination, multiplied by 8.33 yielded the weight percent of calcium carbonate. This was the amount of calcium carbonate equivalent to the percent carbon removed during acidification.

TABLE 2. Average values of sedimentary statistical properties for the sand flats and sea grass beds of the geographic divisions of St. Andrew Bay: graphic mean (M_g); inclusive graphic standard deviation (SD); inclusive graphic skewness (SK_1); graphic kurtosis (K_g); total carbon (TC); organic carbon (OC); and carbonate ($CaCO_3$).

Area	Sample No.	M_g ϕ	SD	SK_1	K_g	TC %	OC %	$CaCO_3$ %
<i>Sand flats</i>	89	2.08	0.58	-.13	1.15	0.56	0.40	1.30
West Arm	17	2.03	0.58	-.04	1.29	0.28	0.21	0.58
East Arm	21	2.19	0.55	-.12	1.17	0.55	0.36	1.59
Central Bay	7	2.20	0.42	-.05	1.16	0.27	0.16	0.90
Lagoon	25	1.96	0.50	-.18	1.14	0.39	0.17	1.81
Bayous	19	2.13	0.78	-.19	1.13	1.16	1.03	1.08
<i>Sea grass beds</i>	59	2.12	1.10	-.15	2.18	1.05	0.75	2.52
West Arm	13	2.31	1.53	+.37	3.54	1.04	0.71	2.56
East Arm	18	2.11	0.88	-.38	2.14	1.38	0.98	3.31
Central Bay	7	2.18	0.64	-.06	1.69	0.57	0.41	1.29
Lagoon	13	2.04	0.55	-.25	1.47	0.70	0.43	2.39
Bayous	8	1.91	0.91	-.35	1.63	1.31	1.07	1.98

Sedimentary Properties

All intertidal sediment samples from St. Andrew Bay, including those from contiguous bayous, consisted of 82 to 99% sand-sized grains with the exception of Station 29 which contained 77%. The predominant sediment type was fine-grained quartz sand with lesser amounts of medium-grained sand; both of these types occurred in each division of the bay and bayous.

Sedimentary parameters for the physiographic divisions of the intertidal sediments of the bay and for the intertidal zone on the Gulf of Mexico (47 samples) adjacent to West Pass were compared (Table 1). The average intertidal sediment of the bay, including those of sea grasses and sand flats, was a fine-grained quartz sand moderately well to moderately sorted, with near-symmetrical to negatively coarse-skewed, and leptokurtic to very leptokurtic size-frequency distributions. At East Pass, however, sediment properties (Table 1) were intermediate between those of the Lagoon and those of the intertidal zone of the Gulf of Mexico. These sands were coarser than the Lagoon sands and contained less organic matter (Figs. 2A and C). This may have resulted from transport of coarser sands from the Gulf of Mexico into East Pass from the southeast and possibly from scouring by tidal currents.

Sedimentary parameters of sea grass beds and sand flats were also compared (Table 2). On the average, sediments of all sea grass beds were slightly finer-grained, less well

sorted, with their size-frequency distributions slightly more negatively skewed and very leptokurtic. However, comparison by divisions of the bay indicated that the intertidal sand flats of the East Arm and Central Bay had a finer graphic mean grain-size than the sea grass beds from the same area. In the bayous where seagrass beds and sand flats were present, all the sand flats had finer-grained sediments. Within the sea grass beds sorting was consistently poorer, with a slightly more negatively skewed and more leptokurtic size-frequency distribution.

The average particle size of the *Thalassia* beds (2.07ϕ) was similar to the mean of the bay sand flats and the mean particle-size of the *Halodule* beds (2.12ϕ) was the same as the mean of the sea grass beds. The *Halodule* substrate was better sorted, more coarsely skewed, and more leptokurtic than the *Thalassia* beds. In the mixed beds grain size was the same as the *Halodule* beds, but the substrate was even more poorly sorted, more negatively coarse skewed, and more leptokurtic than the sediments of either the *Halodule* or the *Thalassia* beds.

Two fractions, very coarse sand (0 to -1ϕ) and granules (-2 to -1ϕ), represented a variable proportion of the sediment particle-size distributions that occurred in the intertidal zone of the bay. Sea grass beds (Figs. 2C and 3C) had a higher proportion of these fractions than did the sand flats (Figs. 2A and 3A). These fractions contained organic debris, including sea grass

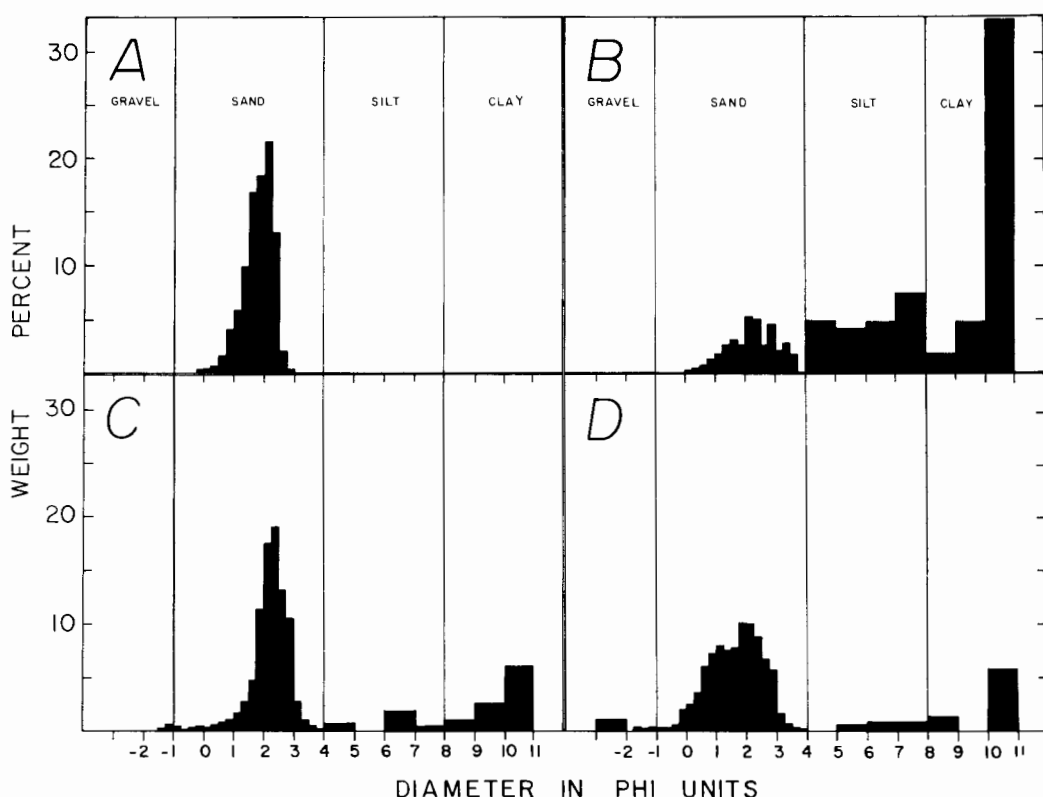


Fig. 3. Grain-size frequency distributions of sediments from the West Arm of St. Andrew Bay: A. Well-sorted sediment with leptokurtic size-frequency distribution from sand flat on south shore of West Arm; B. Clay ball from intertidal zone north of Hathaway bridge showing prominent crude mode between 10–11 ϕ in clay fraction; C. Poorly sorted sediment with bimodal, extremely leptokurtic size-frequency distribution and a 10–11 ϕ mode in the clay fraction from *Halodule-Thalassia* bed; D. *Halodule-Thalassia* bed on north shore showing the spread of particle size and 10–11 ϕ mode in the clay fraction.

fragments, and sand which were clear to frosted, milky, and subangular to subrounded quartz grains. Colors ranged from dark greyish-olive to yellowish-gray (Munsell 1929–65; Kelly and Judd 1965). The sands may be relict deposits reworked from the late Pleistocene embayment of the area (Cooke 1939).

The intertidal sea grass beds had a silt-clay content of 2.9% (57 samples) compared to an average silt-clay content of 0.8% (92 samples) in the sand flats. The average content of silt-clay would have been less except for the presence of clay in West Arm and on the north shore of Central Bay. In the sea grass beds, on the west side of the arm, the clay content varied by stations from 2.4 to 14.7%, and on the east side from 3.0 to 7.1%. There was no clay in the sand flat

sediments from Alligator Bayou to Courtney Point on the west side, but at the remaining stations in the arm it was present in quantities from 1.0 to 2.9%. Because of the fine sediment in the West Arm, about one-half of the particle-size distributions of the sand flats were positively skewed and all particle-size distributions of the sea grass beds were positively skewed. Most of the particle-size distributions of the bay sands were negatively skewed to varying degrees. Clay did not occur elsewhere in the bay intertidal zone, but silt was present, although it exceeded 1.0% in only a few samples.

Determination of moisture content was made only at stations in West Arm. The water content (21 samples) averaged 31%, by dry weight, in the sand flats on the west and east side of the arm despite higher clay

content on the east side. Within the sea grass beds the water content (16 samples) averaged 43%.

The carbon content, either as organic or carbonate carbon, varied widely in the intertidal zone of the bay. Organic carbon ranged from a low of 0.01% at a station in the Lagoon to a maximum of 7.4% at one in Watson Bayou. In Central Bay, one sample exceeded 1% organic carbon, while in East Arm and West Arm 20 stations exceeded this value. All of the bay divisions except Central Bay where the content was slightly higher contained at least one station with less than 0.5% organic carbon. The average content for organic carbon for all stations in the intertidal zone was 0.5% (148 samples) and for sediments on the subtidal slopes of the bay it was 1.3% (115 samples). In the intertidal sand flats organic carbon was 0.40% (87 samples) and in the sea grass beds 0.75% (57 samples). In the east and west arms of the bay where the principal industrial development was on the north shores, organic carbon averaged 0.6% on the north shore and 0.4% on the south shore of West Arm and 0.9% and 0.5% on the north and south shores of East Arm, respectively.

Calcium carbonate content of the sediments, indicative of shell material and carbonaceous epiphytes, was highest at Lagoon and East Arm stations and lowest at Central Bay stations. The only relationship between sediment size and carbonate was observed at a station in the lagoon where the maximum carbonate content of 14.3% occurred in sediment with a gravel content of 18%. The average carbonate content of the sea grass substrates, generally over 1.0% was almost double that of the sand flats.

Discussion

Though mature subtidal sea grass beds develop a finer-grained substrate than surrounding unvegetated areas (Wood et al. 1969) by entrapping saltating grains, suspended matter, and terrestrial debris swept into the bay, this may not uniformly be the case in the intertidal sea grass habitat subject to subaerial exposure by fluctuating tides and wave action. Although the graphic mean particle-size of the sea grass substrate

for the bay is slightly finer than that of the sand flats, by comparison of physiographic divisions it is finer only in West Arm and Lagoon. In East Arm the sand flats are finer-grained. In Central Bay sediments of sea grass beds and sand flats are approximately of equal grain-size. Lack of consistent distinction in mean particle-size between the sand flat and sea grass bed sediments probably resulted from the variation in the grain-size of sands eroded from marine terraces surrounding the bay and from the differences in tidal current velocities in the more constricted channels. In West Arm the finer-grained and less well sorted sediments of the sea grass beds resulted from a nearby source of fine sediment with a 10.5 ϕ mode in the clay fraction (Figs. 3C and D). The effect of the clay was to shift the skewness of the sediment distribution from negative symmetrical to positive strongly fine-skewed. The clay is probably derived from the breakdown of numerous clay balls and clay fragments, which have accumulated in the intertidal zone on the west shore immediately north of Hathaway Bridge. The clay balls were trimodal sand-silt-clay characterized by a very prominent mode within the 10 to 11 ϕ interval and minor modes in the sand and silt fractions (Fig. 3B). This clay was derived from one of the submerged outcrops of an older bay deposit eroding on the bay slopes.

Since the intertidal zone is subject to direct wave and current action, one would expect the concentrations of organic matter to be less than in a fully developed subtidal sea grass bed. Even in intertidal sea grass beds the presence of the sea grass itself should ameliorate the impact of wave and current on the substrate. Wood et al. (1969) in a study of carbonate specimens in a subtidal *Thalassia testudinum* bed at St. Catherine's Beach, Bermuda, found an increase in the silt-clay fraction (4.8%) over the adjoining unvegetated habitat (0.1%). In these beds the average content of organic matter (3.5–4.9%) was 2-fold higher than that of the surrounding sand flats (1.5–2.6%). Marshall and Lukas (1970) found in undisturbed plots in subtidal *Zostera marina* beds, a detrital substrate in a Rhode Island estuary, an average silt-clay content of 14% and 1.25% organic carbon in the upper centimeter. In

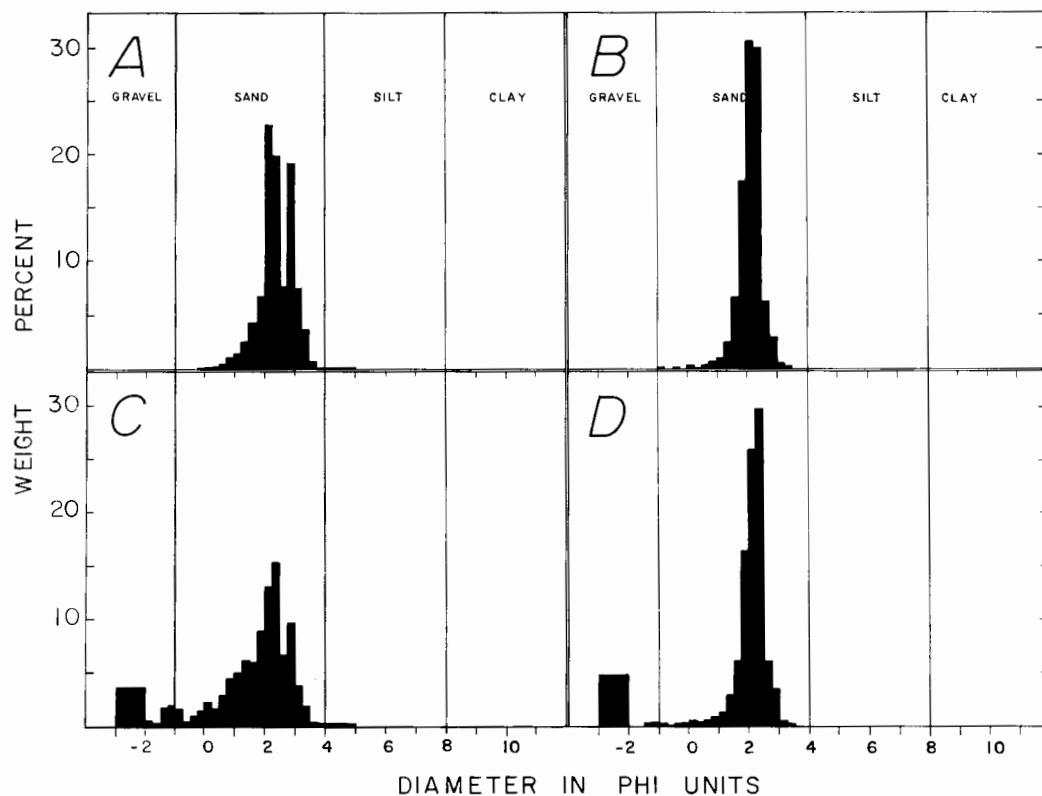


Fig. 4. Grain-size frequency distributions of sediments from East Arm of St. Andrew Bay: A. Moderately well sorted sediment with near symmetrical, mesokurtic size-frequency distribution; B. Well-sorted sediment with coarse-skewed, leptokurtic size-frequency distribution from sand flat on south shore; C. Moderately sorted sediment with strongly coarse-skewed, leptokurtic size-frequency distribution from *Halodule-Thalassia* bed on north shore; D. Well-sorted sediment with strongly coarse-skewed, extremely leptokurtic size-frequency distribution from *Halodule-Thalassia* bed on south shore.

St. Andrew Bay sediments on the subtidal slopes had an average silt-clay content of 2.9% and an organic content of 1.3%; in the intertidal zone the average silt-clay content of sea grass and sand flat sediments was 1.8% and the organic carbon content 0.5%. The 2.6-fold higher content of organic carbon on the subtidal slopes correlated with a decrease in particle size of 2.09 to 2.70 ϕ . In the St. Andrew Bay intertidal sea grass beds the organic carbon content was 1.9-fold greater than in the sand flats. Although the content of organic matter, based on the carbon content as an index, was much lower in St. Andrew Bay sediments than the carbonate sediments at St. Catherine's Beach, the ratio of organic matter in sea grass to sand flat substrates was essentially similar. Less differences were found between these habitat types at Bayou stations.

The effect of the presence of sea grass on the organic content of sediments in St. Andrew Bay is best illustrated by comparing sand flats and sea grass beds of Central Bay and Lagoon (Table 2) because these areas are less affected by organic debris derived from industrial pollution (EPA 1975) than East and West Arm stations where sea grass beds contained up to 2.7 and 3.4-fold higher organic carbon levels, respectively, than adjacent sand flats. Little difference was found in the average carbon content between sand flat sediments of Central Bay and those of the Lagoon; or between the higher concentrations found in the sediments of sea grass beds in Central Bay and Lagoon. However, the carbon content was 2.5-fold greater in the sea grass sediments than in those of the sand flats in Central Lagoon; a similar increase was also ob-

served between Lagoon sea grass and sand flat sediments.

Areas of East and West Arms of St. Andrew Bay are subject to various types of pollution other than sheetwash along shore and outflows from bayous during storms (EPA 1975). East Arm has been subjected to the heaviest and longest period of pollution from such sources of industrial wastes as oil, chemicals, wood chips, effluent from waste water treatment plants, and secondary treatment of Kraft pulp mill effluent (EPA 1975). Untreated and treated domestic wastes have contributed organic matter to the bayous and to the shores of East and West Arms in excess of the amount received in other parts of the bay (EPA 1975). Within the intertidal zone, high concentrations of organic matter in coarse-grained sediments are a good index of pollution, as the more coarse-grained the sediment, generally, the less organic matter it contains (Emery 1960). The north shores of the East and West Arms are close to the sources of pollution, and data reflect that stations here were higher in organic matter than the south shores or any other area sampled within these physiographic divisions.

In the East Arm, sea grasses on the north shore were absent in the adjoining bayous except for Pitt Bayou near Dupont Bridge and a few intertidal stations. All bayous and intertidal stations on the south shore supported sea grasses. *Halodule* was the dominant species in the intertidal stations of East Arm; less than half of these stations had both *Halodule* and *Thalassia*. *Halodule* was also the predominant sea grass on the north shore of West Arm and East Arm. In West Arm a few stations with a dominance of *Thalassia* were found on the south shore. In the other physiographic divisions a mixture of the two sea grasses was most common. Lack of sea grass in bayous on the north shore of East Arm most probably resulted from the high turbidity and anoxic conditions associated with the polluted sediments in this area.

Watson Bayou adjacent to the Kraft pulp mill (Fig. 1) was the most highly polluted area and was devoid of sea grasses. At one station the total carbon and organic carbon content of the sediment were slightly over 7%. These values were observed to be the

highest and occurred in a coarse-grained sediment (1.86ϕ) which is comparable to that of the adjacent intertidal zone in the Gulf of Mexico. In addition, in the fall the first strong north winds coincident with low tides, appear to upwell the anoxic water over the hydrogen sulfide laden bottom sediments, a phenomenon which has resulted in numerous fish kills. As noted previously, this disparity between grain-size distribution and organic carbon content is indicative of a polluted sediment in the bay intertidal zone.

Sediments near the mill were not well sorted despite containing little gravel or silt; they show a greater range in standard deviation (Fig. 2B). Deposition of debris apparently has suppressed the predominant fine-grained mode of the intertidal bay sands resulting in poorly sorted, coarse-skewed, barely leptokurtic distributions (Fig. 2D). Differences in the sediment distribution on the heavily polluted north shore compared to the less polluted south shore of East Arm are illustrated in histograms of the sea grass substrates (Figs. 4C and D) and sand flat substrates (Figs. 4A and B).

The average carbonate content of the sea grass beds was 1.9 times higher than that of sand flats (Table 2), but less than half as much as the content in the subtidal slopes of the bay. The accumulation of carbonate in sea grass beds, should it survive erosion by tidal currents, wave action, and solution, could aid in the interpretation of paleoenvironments as minor limestone features in sandstone deposits (Petita and Gerhard 1977).

Summary

The sediment type present in all the intertidal *Halodule-Thalassia* sea grass beds and sand flats of St. Andrew Bay was a fine-to medium-grained quartz sand. The graphic mean particle-size of all sea grass beds was slightly finer than those of the sand flats, but by comparison of physiographic divisions of the bay, West Arm and Lagoon sand flats were finer-grained. In Central Bay average particle-size was about the same in the sea grass and sand flat sediments, but in East Arm and Bayous particle-size was finer in the sand flats. No significant difference was found in the mean grain-size of sediments

containing a single species or in sediments containing both species of sea grass. The sea grass substrate was less well sorted and the size frequency distribution more negatively skewed and more leptokurtic than the sand flat substrate.

In all the sea grass beds the average organic carbon was higher by 1.9 times that of the sand flats and in the polluted areas as high as 3.4 times, although the sea grass mean particle size varied only slightly from the sand flat mean. In West Arm the water content of the sea grass beds was 12% higher than in the sand flats.

The intertidal sea grass substrates were coarser-grained and contained less organic carbon and carbonate than the subtidal beds. In the polluted bayous, and at adjacent intertidal stations, on the north shore by the pulp mill, sea grasses were absent. Near this area where sea grasses were present *Halodule* was the dominant species.

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